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Sedimentation of Cidra Reservoir Puerto Rico

Soil Conservation Service
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Highlights

The Cidra Reservoir, put into service in 1946 by the Puerto Rico Aqueduct and Sewer Authority, is part of the municipal water supply system for the metropolitan area of San Juan and provides about 33 percent of the water requirements. It has an 8.12-square mile (mi^2) drainage area and is situated in the mountains of east-central Puerto Rico. The average annual rainfall is about 70 inches, and the average annual runoff is 28 inches.

The original storage capacity of the reservoir was 5,325 acre-ft. In 25 years of storage 520 acre-ft of sediment has been carried into the lake, resulting in a loss of nearly 10 percent in storage capacity. The average dry weight of sediment samples was 35.11 pounds per cubic foot (764.7 ton/acre-ft). Sediment has been deposited in the reservoir at an average annual rate of 2.7 acre-ft per square mile of drainage area (about 3.3 ton/acre). The resulting average annual storage loss is 20.8 acre-ft, 0.39 percent of capacity. At the present rate of sedimentation the remaining life of the reservoir as a body of water is about 230 years.

Soil erosion on the steep agricultural lands is the principal source of sediment. The annual soil loss from erosion averages 43.3 acre-ft for the watershed.

Improved land use and conservation treatment practices offer the best solution to the sedimentation problem. Needed practices include improved crop rotations, contour cultivation, stripcropping, crop residue management, vegetative and rock barriers, water disposal systems, and fertilizing and liming. An increase in the acreage of improved pasture, well-managed coffee land, and woodland with a decrease in the acreage of cultivated crops would help reduce the amount of sediment reaching the reservoir.

Acknowledgments

The Puerto Rico Aqueduct and Sewer Authority staff, Wilfredo Vivoni, director, provided valuable cooperation and assistance, particularly in supplying equipment and manpower for field surveys and in supervising field operations for the eradication of waterhyacinths. Staff members assisting were Jose Goitia and Arnaldo Sepulvada. The Soil Conservation Service, Caribbean Area staff, Edward R. Keil, director (ret.), provided technical and administrative support and assistance.

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Sedimentation of Cidra Reservoir Puerto Rico

by James L. Hunt, *geologist*, Soil Conservation Service

Cidra Reservoir, located in the mountains of east-central Puerto Rico, was studied to determine the rate of storage loss resulting from the deposition of sediment derived from soil eroded within the reservoir watershed. The Soil Conservation Service (SCS), U.S. Department of Agriculture, in cooperation with the Puerto Rico Aqueduct and Sewer Authority (AAA), carried out the survey in November 1971. All available data from an earlier unpublished survey[1] were provided by AAA for use in this survey.

Results reported in this technical paper provide a basis for estimating the total amount of soil eroded from the 8.12-mi[2] drainage of the reservoir since 1946[2] and for projecting the usable life of the reservoir under the current erosion rate.

The survey methods and the calculations of erosion rate and sediment yield are useful for studying sedimentation of reservoirs in similar subtropical areas.

The erosion rate depends on physical and mineral characteristics of the soil and rock, on land use and cover, on length and steepness of slopes, and on the intensity, duration, and frequency of rainfall. Sediment movement is controlled by topography; stream patterns, dimensions, and flow; and rainfall and runoff.

The useful life of a reservoir can be determined by comparing the sedimentation rate with its remaining storage capacity. Such rates are indicators of watershed conditions, such as changes in vegetative cover, land use, and weather, and the effects of erosion control measures. When the loss of storage capacity reaches a critical point, a decision must be made to either abandon or reclaim the reservoir.

Consideration of annual erosion rates in conjunction with land use practices can serve as a basis for developing an erosion-reducing land treatment and soil conservation program in the watershed and in similar adjacent areas that can extend the life span of reservoirs like this one.

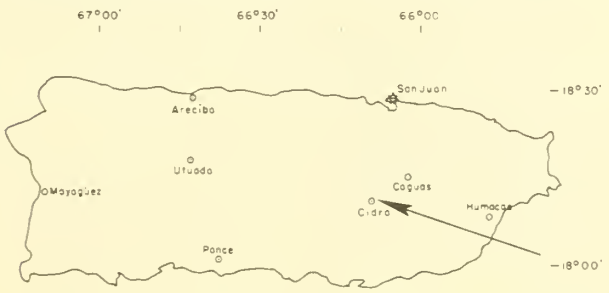


Figure 1.—Location of Cidra watershed, Puerto Rico.

Reservoir description

Cidra is part of a project of the Puerto Rico AAA, the island's only public water supply authority. The southwest end of the reservoir is located 0.6 mi (1 km) east of the town of Cidra in east-central Puerto Rico (fig. 1). A dam was constructed about 1,000 ft (0.3 km) downstream from the confluence of the Río Bayamón and the Quebrada Prieta. It created a lake of 274.4 surface acres (283.2 cuerdas[3]) extending generally southward through the lower Río Bayamón into the Río Sabana valley. A major lake arm extends a short way eastward into the Río Bayamón (fig. 2). The concrete dam is 410 ft (125.0 m) long and 65 ft (19.8 m) high. The abutments to the dam consist of earth and rockfill embankments and concrete cutoff walls. In the left abutment the cutoff wall is 147 ft (44.8 m) long and joins a concrete nonoverflow section 131 ft (39.9 m) long at its crest width.

Manually controlled inlet and outlet gates and their controls are housed in the left nonoverflow section. Inlets are at elevations[4] of 1,253.2 ft (382.0 m) and 1,292.7 ft (394.0 m). Outlets are at 1,270.5, 1,287.8, and 1,305.0

[1]Guzman, R. A. Lago de Cidra, localizacion de hitos y trazado de perfiles tranversales para futuros estudios de aterramiento. P.R. Aqueduct and Sewer Auth., unpublished. 1964.

[2]Various reports indicate construction was completed in 1946. The exact date the reservoir was filled was not recorded. For sedimentation computations, 1946 was used as the base year.

[3]A Puerto Rican surface measure; 1 cuerda equals 0.97 acre.

[4]Elevation above sea level.

ft (387.2, 392.5, and 397.8 m respectively). A reservoir drain outlets at 1,254.7 ft (382.4 m). Manually controlled outlet gates release water by gravity through the left wingwall into the spillway and then into the river below.

A permanent caretaker lives at the dam and has both a telephone and a two-way radio.

Water flow and use

The original reservoir storage was computed[5] to be 5,325 acre-ft (6.6 Mm^3-million cubic meters) or about 1.7 billion gal. Effective or live storage, the volume of usable water between the 1,322.2- (403.0 m) and 1,270.0-ft (387.1 m) elevations, is 4,965 acre-ft (6.1 Mm^3) or about 1.6 billion gal. Dead storage, between the 1,270.0- and 1,253.2-ft (382.0 m) elevations, is 360 acre-ft (444,240 m^3).

[5]Because data of the original site topography and reservoir capacity were not available, data from the 1964 study by Guzman were used as a basis for estimating original capacity. The 5,325 acre-ft figure compares favorably with original capacity values cited by Sheda and Legas (1968) and Arnow and Crooks (1960).

Water flows by gravity until the reservoir water level falls below the 1,270-ft elevation. A reservoir drain system can draw water down to the 1,253.2-ft elevation. Maximum design discharge through the spillway computed to the top of the nonoverflow section is about 24,600 ft^3/sec. Maximum discharge through the controlled outlets, not including the reservoir drain facility, is 86.6 ft^3/sec (2.5 m^3/sec).

The Cidra impoundment is a holding reservoir. Water released from the lake flows north in the Río Bayamón channel to a diversion dam 8.7 mi (14.0 km) downstream near the northwest boundary of the Aguas Buenas municipality. At the diversion the water enters two pipelines and is carried by gravity to the Guaynabo treatment plant.

Lake Cidra was put into service in 1946 and is part of the municipal water supply system of San Juan and the surrounding cities of Guaynabo, Bayamón, and Carolina and surrounding towns of Trujillo Alto, Cataño, Toa Alta, Toa Baja, Loíza, Río Grande, and part of Dorado. In 1960 it supplied about 33 percent of the water needs for this metropolitan population of 648,000 (Schneider 1968).

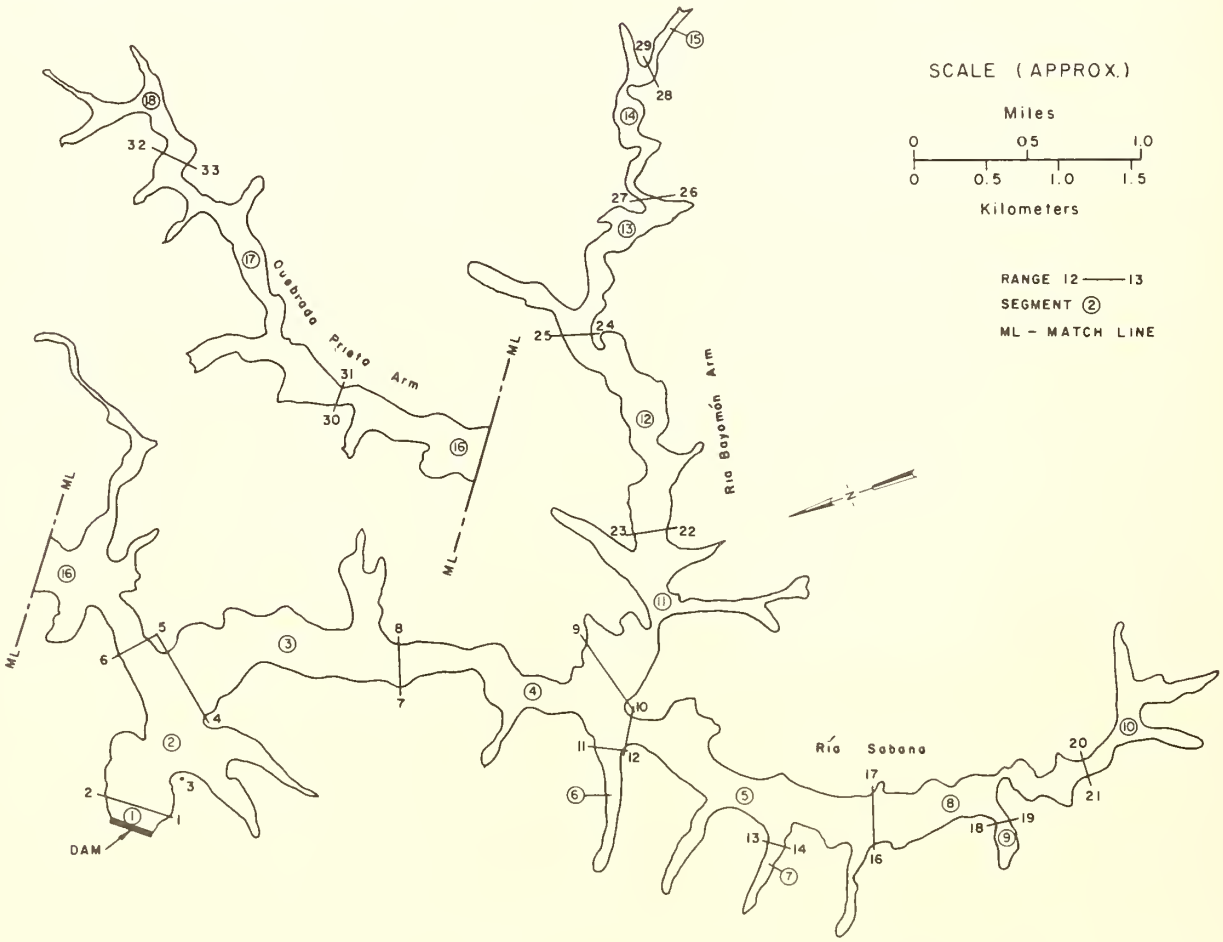


Figure 2.—Cidra Reservoir, 1971.

Water budget

Inflow, evaporation and seepage, sediment deposition, and outflow either add to or substract from the amount of water actually available in the reservoir. The space occupied by sediment deposits is also considered. The net amount makes up a budget of water actually available for use at a given time.

The maximum storage available in 1971 was 4,821 acre-ft. The minimum amount of water needed to meet potential consumptive demands plus corrections for losses due to evaporation and seepage in 1971 was determined to be 22,342.7 acre-ft or 51.6 in. of surface runoff. The projected average surface runoff in the Cidra drainage is calculated to be 28 in./yr; this is equivalent to 12,125 acre-ft of water. If full consumptive demands were to be met, the total of the annual inflow and storage capacity would last only about 9.1 months. Cidra is considered an auxiliary reservoir and is not expected to meet these calculated consumptive demands on a regular yearly basis. However, during 1967 the island had an 8-month drought during which runoff for the watershed was figured to be only 4.8 in. or 2,086 acre-ft for the year. The maximum duration of the reduced inflow plus storage to meet these potential demands would have been only 3.7 months. The reservoir did in fact almost run dry in 1967 (Goitia 1970).

Noxious plant infestation

Cidra Reservoir had been in use for about 8 years when waterhyacinths, *Eichornia* spp., began to infest the reservoir in 1955. By 1969 the infestation covered the entire lake,[6] and a control program was attempted, using both airboats and motorboats equipped with herbicide sprayers. Motorboats could not even penetrate the massed growth and airboats had only limited success. In mid-1970 the herbicide phase was abandoned in response to widespread public concern over the potential side effects of the chemicals on other biota.

[6] An acre of waterhyacinths occupies about 700 ft^3 of space (displaces 5,240 gal of water). They reproduce rapidly, with single plants producing as many as 65,000 seedlings.

Then a "bulldozer" was used to break the waterhyacinth growth into islands and push them to removal areas (figs. 3 and 4). The bulldozing cleared enough of the growth so that the survey could start in mid-1971. However, floating islands, randomly blown across the lake by shifting winds (fig. 5), frequently caused problems during the surveying. Bulldozing was stopped in December 1971 when 90 percent of the lake surface had been cleared.

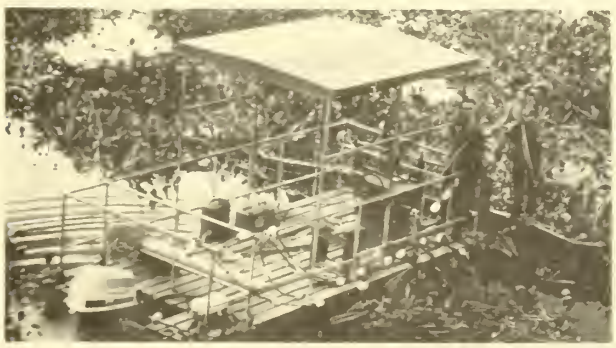
Watershed description

Most of the Lake Cidra watershed lies within the municipality of Cidra and includes parts of Arenas, Bayamón, Beatriz, Ceiba, Monte Llano, and Sud barrios (wards). Part of the town of Cidra is in the watershed. A small part of the drainage, the Cañaboncito barrio and the headwaters of Quebrada Prieta, is in the municipality of Caguas.

Three major tributaries form the watershed of the reservoir: the Quebrada Prieta, Río Bayamón, and Río Sabana. The watershed covers 5,199 acres or 8.12 mi^2 (13.1 km^2) including the 274-acre lake (fig.6). The highest elevations, both 1,800 ft (548.6 m), are 0.4 mi (0.64 km) southwest of Beatriz Adventro School in the Río Bayamón headwaters and 0.15 mi (0.25 km) north-northeast of the ward boundary intersections of Arenas, Rincón, and Sud. The lowest elevation, 1,250 ft (381 m), is the reservoir bed at the base of the dam.

Climate

Convectional rains, a result of condensation of moisture-laden air currents that have been deflected upwards, account for most precipitation in the Cidra watershed. Rainfall intensity and amount increase as elevation increases. But heavy rains are usually of short duration, and excessive surface runoff is minimized by the rapid evaporation resulting from high temperature, low humidity, and an almost constant air circulation. Tropical storms and hurricanes affect the area about every 5 years. They may cause several hours of torrential rains or several days of intermittent rains. The heavier rainfall



Figures 3 and 4.—"Bulldozer" is a raft with sealed steel drums for floatation and has a pipe-and-wire-mesh blade that can be raised or lowered manually with a boat trailer winch. A 100-hp engine propels the raft.

usually accelerates soil erosion and sharply increases sedimentation.

Mean annual rainfall ranges from 65 to 75 in. with an average of 70 in. (fig. 7). Rainfall is usually low from November through April and high during May, August, September, and October. The maximum rainfall recorded was during a hurricane in September 1928 when as much as 13 in. was recorded in one 24-hr period.

The one stream gage in the watershed is located well downstream from the dam (see table 1), so overall watershed estimates are based on data from other Puerto Rican watersheds with similar drainage conditions. The average runoff for the Cidra watershed is calculated to be 28 in./yr; in the headwaters it is estimated to be about 42 in./yr.

Figure 5.—Waterhyacinth islands are blown upstream (right) from the dam by afternoon offshore winds. Diurnal changes in wind direction over the reservoir surface, offshore during the morning hours and onshore during the afternoon, cause continuous movement of plant islands.

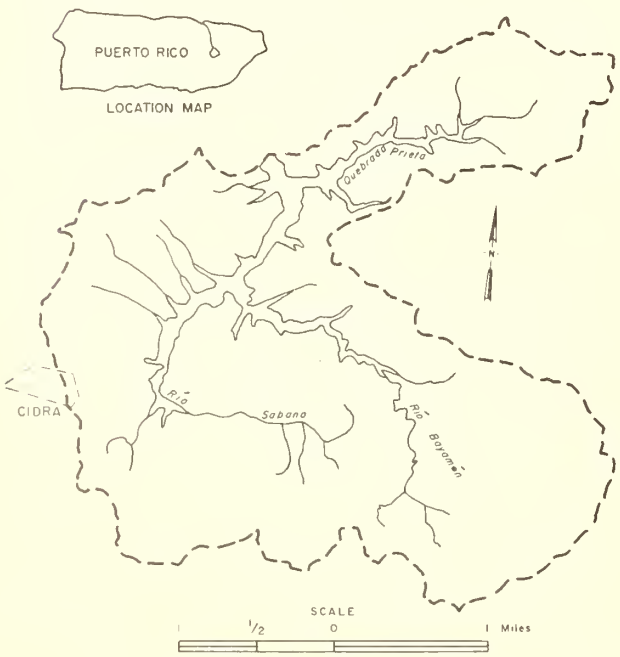


Figure 6.—Cidra watershed.

Topography

The watershed is generally mountainous. Valley walls are moderately steep with nearly half the watershed having slopes of 20 percent (9.0 degrees) or greater. Hilltops are moderately rounded ridges or knobs.

Stream valleys in the uplands have very narrow or virtually no flood plains because of the steep gradients and rapid water discharge. The gradient of the major tributaries averages 0.0378 (equivalent to a change in elevation of about 200 ft/mi). Runoff and precipitation have caused a deeply incised, dendritic stream drainage pattern. The average slope is 30 percent (see table 2).

Geology

Rock formations are generally of Cretaceous age and younger. Soils are of volcanic origin, deeply weathered by the subtropical climate, and easily erodible. The only major geologic separation, the Río Arroyata faultline, is south of the town of Cidra and along the boundary between soil associations 6 and 7 (fig. 8). Geologic knowledge is insufficient so far to separate the component rock formations and show them on a map. No identifiable fossils have been found within rock formations in the Cidra watershed.

One of the oldest rock formations in the watershed, called formation J,[7] has been studied by Pease and Briggs (1960). They describe the rock as occurring as large boulders that crop out from an east-west anticlinal crest across the southern part of the watershed. Similar rock occurs in the northwestern part and in the area

[7]This is a temporary designation until the formation is given a formal geologic name.

Table 1.—Monthly runoff at Río Bayamón stream-gaging station

Month	1965	1966	1967	3-year average
	in.	*in.*	*in.*	*in.*
January	0.41	0.81	0.44	0.55
February	.12	.38	.40	.30
March	.10	.67	.28	.35
April	.14	1.09	.17	.47
May	2.58	3.62	.19	2.13
June	.94	.70	.11	.58
July	.78	.63	.16	.52
August	3.46	.45	.49	1.47
September	1.59	1.27	.16	1.01
October	1.08	2.30	.14	1.17
November	1.44	1.05	.29	.93
December	7.26	1.95	.14	3.12
Total	19.90	14.92	2.97	12.60

between the Quebrada Prieta and Río Bayamón arms of Lake Cidra. The rock consists chiefly of dark green-gray volcanic breccia intercalated with bedded tuffaceous sandstone.

Other kinds of rock Pease and Briggs described as present in the watershed are hydrothermally altered rock, alluvial terrace deposits, and lateritic deposits. The altered rock, composed chiefly of quartz and sericite, is exposed along the south side of the lake, in the area between the Río Sabana and Río Bayamón arms, and in most of the drainage area of the Quebrada Prieta arm. Alluvial terrace deposits of sands and gravels occur near the lake. Deposits are randomly distributed, generally below 1,440 ft (438.9 m). Lateritic deposits result from chemical weathering and have not been distinguished from underlying bedrock formations on geologic maps.

Soils

Each of the two associations in the Cidra watershed (fig. 8) generally contains a few major soils and several minor soils in a pattern that is characteristic although not uniform in every respect. Within any one association the soils differ from each other in some properties such as slope, depth, stoniness, and natural drainage. Although a soil association map shows the location of characteristically associated soils, it does not show the patterns of soils within an association nor does it indicate the kind of soil at a particular place.

Each association is named for its major soil series, but it also includes other soils. Some of these soils also occur in other soil associations but in different patterns or proportions.

In the following descriptions of soil associations in the Cidra watershed, the associations are numbered according to the numbers in figure 8. The approximate acreage of each soil series and the proportionate extent of each association are shown in table 3.

No. 6.—Mucara-Caguabo-Rio Arriba association

This association consists of gently sloping to very steep, well drained to moderately well drained, medium acid to mildly alkaline, loamy to clayey soils on side slopes and ridgetops and on alluvial fans and terraces at the base of dissected uplands. This association occupies about 24 percent of the total acreage of the watershed.

The landscape is mountainous with many narrow ridges and is highly dissected by intermittent streams. The association extends in an east-west belt along the southern part of the watershed.

Mucara soils are clayey, moderately deep, slightly acid and medium acid, and well drained, and are on moderately steep to very steep hills. They formed in materials weathered from volcanic rock. They make up about 50 percent of the association. Caguabo soils are loamy, shallow, slightly acid throughout, and well

Table 2.—Distribution of land slopes

Slope	Area	Extent in watershed
	acres	*percent*
0–3 percent	471	9.1
3–10 percent	576	11.1
10–20 percent	1,310	25.2
20–50 percent	2,358	45.3
Over 50 percent	210	4.0
Total[1]	4,925	94.7

[1]Remaining 274 acres in watershed are water areas.

Table 3.—Acreage of soils and proportionate extent of soil associations in the Cidra watershed

Soils	Area	Extent
	acres	*percent*
Association No. 6:		
Mucara loam	629.0	
Caguabo loam	314.5	
Rio Arriba clay	188.7	
Others	125.8	
Total	1,258.0	24.2
Association No. 7:		
Humatas clay	2,016.8	
Consumo clay	916.8	
Daguey clay	550.0	
Others	183.4	
Total	3,667.0	70.5
Water areas	274.0	5.3
Total	5,199.0	100.0

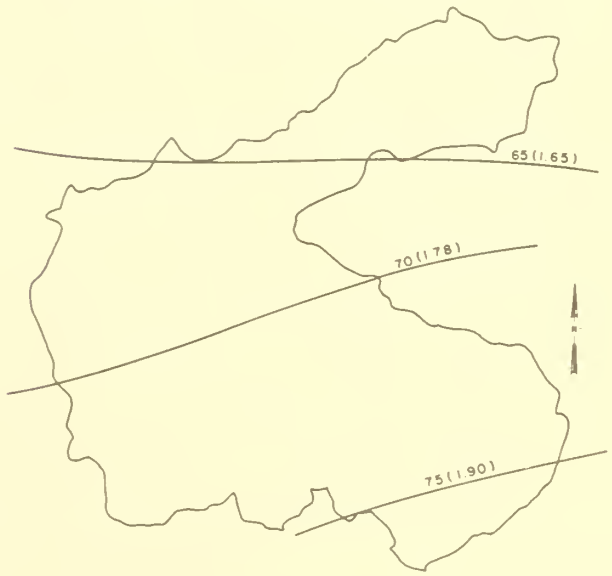


Figure 7.—Distribution of annual rainfall in inches (meters).

drained, and are on very steep side slopes and mountaintops. They formed in material weathered from volcanic rock. They make up about 25 percent of the association. In some areas, more than three-quarters of the surface area of these soils is covered with stones. Rio Arriba soils are clayey, deep, medium acid to mildly alkaline, and moderately well drained, and are on gently sloping to strongly sloping alluvial fans and terraces. They formed in fine-textured sediments of mixed origin. They make up about 15 percent of the association.

Much of this association is in brush and brushy pasture. Food crops are planted in some places. Fertilizers are seldom used. Steep slopes, soil depth, and the erosion hazard are permanent limitations to cultivation for much of this association. The steeper soils are better suited to woodland and pasture, and the more gently sloping soils are better suited to dairy cattle. However, clearing of land for pasture is difficult and costly, and the use of land-clearing machinery is not feasible.

No. 7.—Humatas-Consumo-Daguey association

This association consists of moderately steep to very steep, well-drained, strongly acid and very strongly acid clayey soils on side slopes and ridges of the dissected uplands. This association occupies about 71 percent of the total acreage of the watershed.

The landscape is mountainous with many narrow ridges and is highly dissected by intermittent streams. Lake Cidra is the center of this area.

Humatas soils are clayey, deep, very strongly acid, and well drained, and are on steep and moderately steep terrain. They formed in material weathered from volcanic rock. They make up 55 percent of the association. Consumo soils are clayey, deep, very strongly acid, and well drained, and are on steep and very steep side slopes of strongly dissected uplands. They formed in material weathered from volcanic rock. They make up about 25 percent of the association. Daguey soils are clayey, deep, strongly acid and very strongly acid, well drained, and are on moderately steep side slopes. They formed in material weathered from volcanic rock. They make up about 15 percent of the association.

Much of this association is in pasture. Some of it is planted to food crops. Steep slopes and the erosion hazard are permanent limitations to clean cultivation.

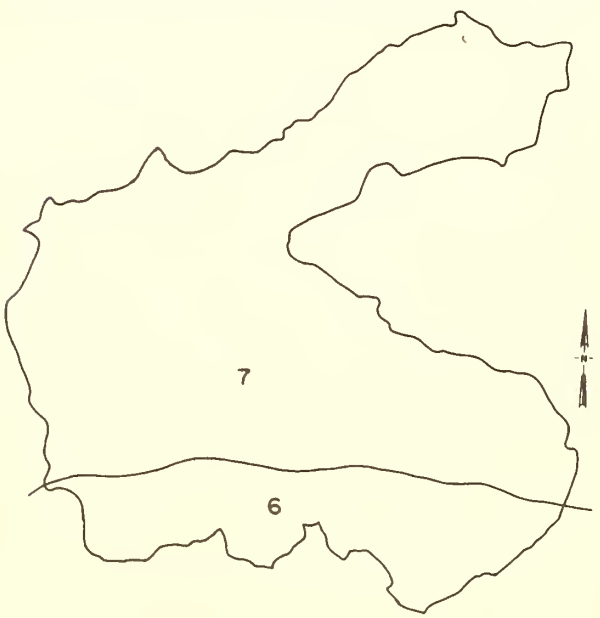


Figure 8.—Soil association map for Cidra watershed. 6—Mucara, Caguabo, Rio Arriba soils. 7—Humatas, Consumo, Daguey soils.

Land use

Originally the watershed was covered by a dense tropical forest. The Indians living in the area developed a primitive type of agriculture, but it is doubtful if enough land was cultivated to increase the erosion rate much above the geologic norm. Because the early Spanish settlers were not interested in farming, there was very little agricultural development during the first 250 years of Spanish occupancy.

The earliest agricultural development was the pasturing of cattle along the river bottoms and on the level uplands. Coffee was introduced from Haiti in 1736. By 1900 large coffee haciendas were well established in the watershed and had replaced most of the virgin forest. Coffee was the most important crop by 1898 although the acreage of pasture was several times larger. Typically, these haciendas were large farms with rows of coffee bushes and shade trees broken by pasture, small areas of other crops, and uncultivated forest and brush land.

The hurricane of 1898 destroyed most of the coffee plantings. Much of the land was replanted to coffee, but this hurricane marked the beginning of the trend toward tobacco and small crops. The hurricane of September 1928 almost wiped out the coffee plantations again. Today, less than 1 percent of the watershed acreage is planted to coffee.

The acreage of tobacco increased rapidly between 1900 and 1930. Since 1930 pasture has been replacing tobacco (as well as sugarcane), particularly on the steep slopes. The acreage of clean-tilled crops (largely tobacco) has declined to less than 6 percent of the watershed area. In the last 20 years, pasture acreage has increased substantially and cropland acreage has declined on the steep slopes primarily because of the high labor costs for cultivation.

Pasture occupies about 68 percent of the watershed; forest, about 11 percent; and cultivated crops, about 12 percent (table 4).

Economy

The agricultural economy for 1971 was assumed to be very similar to that reported in the 1969 Census of

Agriculture (Census Bureau 1972). Census data for the municipality of Cidra are assumed to indicate conditions for the entire watershed. In 1969 the estimated value of all farm products raised and sold in the Cidra municipality was $2.2 million. Crop income was $600,000, and livestock and poultry income was $1.6 million. The annual per farm average income was about $4,000. Of 511 farms totaling 13,670 acres in the municipality, 75 percent are operated by full owners, 9 percent by part owners, 14 percent by tenants, and 2 percent by managers.

In 1973 six cloth manufacturing industries in or near the town of Cidra employed more than 500 persons; collectively they had a payroll of about $1.2 million. Several small businesses, located primarily within the town of Cidra, sell and provide utilities and services. They employ from one to a dozen persons on a full-time or part-time basis.

Game fish in Cidra Reservoir include largemouth bass, bluegill, redear sunfish, channel catfish, guavina, and shrimp. It is estimated that Cidra could produce at least 100 lb of fish per acre per year without diminishing the spawning stock. Present production is below that level because the reservoir is underfished.

Population

Data from the U.S. Bureau of the Census (Census Bureau 1960, 1964, and 1968) were the bases for the 1971 watershed population estimate of 5,890. The average density was 727.2 person/mi^2 of watershed, compared to an average of 792.7 for the entire island. The estimated population of the municipality of Cidra was 23,380. The town of Cidra had an estimated population of 3,640; about 100 of them lived within the watershed.

Table 4.—Land use in the Cidra watershed

Item	Extent
	acres
Cultivated (600):	
Clean-tilled crops, principally tobacco	300
Sugarcane	275
Forage grass	25
Pasture (3,546):	
Improved (good clover)	1,816
Unimproved (native grasses)	1,100
Brushy	600
Coffee	30
Forest (550):	
Large trees	50
Abandoned land (previously in coffee)	40
Brushy	460
Miscellaneous (503):	
Urban areas	35
Rural housing	44
Idle land	150
Water areas	274
Total	5,199

Survey methods

The amount of sediment currently in the reservoir was determined by measuring and computing the remaining water capacity. The location of the 1971 ranges and segments are shown in figure 2.

The 1971 survey was made on the same ranges as in the 1964 study except for ranges 3–4 and 15–16, which were inaccessible for the 1971 study because of heavy, impenetrable masses of waterhyacinths. The area of segments isolated by these ranges was added to adjacent segments for computation. Consequently, the number of segments in 1971 was less than in 1964, and segment numbers are different for the two surveys. Ranges 1–2 and 3–4 were omitted from the 1964 report; hence no comparison with the 1971 figures was possible. The sedimentation figures (of sedimentation by 1964) used in figuring annual sedimentation by 1971 are probably underestimates.

Most of the 1964 range monuments were relocated and used in the 1971 survey. The lake surface served as a reference datum point. Capacity computation for reservoir segments was adjusted to a base datum of 1,322.2 ft (403.0 m). Records show that the water level did not change during the 6-day survey.

On each range a reel of aircraft cable, 3/32-in. (0.24 cm) outside diameter (OD), was secured on the shoreline (alined on the monument) at one end of the range. The cable was trailed by motorboat on line across the range, threaded through a line meter, secured to the opposite shore, and pulled taut to clear the water. On the boat's return along the range, the meter measured the horizontal range distance. The surface between each monument and the closest water edge was measured by hand.

Water depth was measured with a sonic fathometer (fig. 9) capable of measurements to 240 ft (73.2 m). Hand soundings were made with a long pole at the ends of each range to cross-check the fathometer. The scribed "mark" lines on the profile sheet (fig. 10) were made at each 10-ft horizontal interval along the range. The sounding-depth (vertical) scale on the profile paper can be varied as needed while a survey is in progress. The straight, black horizontal line at the top of the paper is for readings of depths to 60 ft. Secondary echoes are sometimes recorded as a lighter profile trace line. When floating islands of waterhyacinths impede the even speed of the boat, flat areas that do not represent actual profile measurements appear on the profile sheet. An example is between stations 70 and 80.

The storage capacity and sediment volume were computed by the Dobson prismoidal formula (Eakin 1936, Gottschalk 1951). An IBM 1130 computer was programed to do the mathematical functions. The results provided the current volume of water in each reservoir segment as well as the total volume in the reservoir. The difference between the current volume and the original volume is the total volume of sediment deposited in the

Figure 9.—Sonic fathometer records range profiles of lake bottoms. Boat operator can see line meter reading and call out regular intervals to be scribed by surveyor on fathogram. Boat operator also makes hand soundings to cross-check fathometer.

reservoir. The sediment volume divided by the original volume gives the percentage of space that sediment now occupies.

A piston-type sampler was used to obtain sediment cores for evaluation tests. It can operate in water as deep as 70 ft (21.3 m). It has a brass sampling tube 30 in. (0.76 m) long by 1⅝ in. (4.13 cm) OD and is driven by a hammer.

Calculation of sedimentation rates

Sediment can settle along the entire drainage system, but waterflow velocity in the system dictates where the heavier deposits will be. The velocity of the sediment-bearing streamflow decreases as it enters the reservoir behind the dam. Larger particles settle first, floating masses of vegetation cause more settling, and the plant leaves and roots remove more particles by surface entrapment. The finest sediment particles remain suspended until the waterflow velocity approaches zero.

Measurement

Capacity loss in percent allows direct comparisons of the changes in volume of individual segments, groups of

Figure 10.—Fathometer profile between 30-ft and 360-ft scribings of range 7-8.

segments, and the entire reservoir. It is used often in this report to indicate in which areas sedimentation is greatest with the resulting loss of water capacity. It also can be associated with time to provide a sedimentation rate.

Sediment deposition should decrease progressively in a downstream direction under ideal conditions, that is, all segments having uniform topography and sediment-bearing inflows.[8] Topography and inflows do vary, however, and the contributing drainage areas vary in size, geology, and kinds of soil. Sediment deposition and the correlative loss of capacity reflect the actual conditions.

Sediment buildup in Cidra since 1946 has reached 519.7 acre-ft (641,310 m^3). This is an average of 20.8 acre-ft of sediment and a 0.39 percent loss in overall reservoir capacity a year. The average sediment deposition per year is 2.7 acre-ft/mi^2 of drainage area (about 3.3 ton/acre). At this rate the remaining life of the reservoir as a body of water is projected to be about 230 years.

[8]This is called the downstream decreasing rule. It is useful for predicting sedimentation volume and rates.

Generally sediment deposition and loss of capacity in the segments of Cidra conform to the downstream decreasing rule. Table 5 shows both measurements for the different segments. A simplified diagram (fig. 11) showing the four major tributaries or arms—Río Bayamón, Quebrada Prieta, Río Sabana, and the remainder of Río Bayamón to the dam—is useful for comparing annual sedimentation in acre-feet and capacity loss in percent for the different segments.

The Quebrada Prieta drainage area, including segments 16–18, is 18 percent of the watershed, and the Río Sabana drainage, including segments, 5, 7–10, is 36 percent. Sediment carried from these drainage areas has caused a 9-percent loss of original capacity in Quebrada Prieta (annual average loss, 0.36 percent) and a 15-percent loss in Río Sabana (annual average loss, 0.61 percent). Sediment volume for Quebrada Prieta is 15 percent of the total reservoir deposits and for Río Sabana, 22 percent. Sedimentation rates conform to the downstream decreasing rule for both arms.

The Río Bayamón drainage area, including segments 11–15, is 36 percent of the watershed. Sedimentation has caused a 15-percent loss in original capacity of this arm

Table 5.—Capacity, sediment accumulation, and capacity loss by segment

	1971 segment No.	Capacity[1]		Sediment accumulation			Annual loss in capacity[7]
		Original[2]	1971[3]	Total volume[4]	Annual volume[5]	Annual weight[6]	
		acre-ft	*acre-ft*	*acre-ft*	*acre-ft*	*tons*	*percent*
Dam to 1–2	1	198.4	186.5	11.9	0.48	370	0.24
1–2 to 4–5–6	2	1,074.1	1,009.6	64.5	2.58	1,970	.24
4–5 to 7–8	3	912.1	857.4	54.7	2.19	1,670	.24
7–8 to 9–10–12–11	4	596.8	534.5	62.3	2.49	1,900	.42
11–12 to end	6	32.6	31.5	1.1	.04	30	.12
10–12 to 13–14, 16–17	5	426.1	375.6	50.5	2.02	1,540	.47
13–14 to end	7	5.6	4.2	1.4	.06	50	1.07
16–17 to 18–19, 20–21	8	254.0	209.9	44.1	1.76	1,350	.69
18–19 to end	9	5.3	4.6	.7	.03	20	.57
20–21 to end	10	43.6	27.9	15.7	.63	480	1.44
9–10 to 22–23	11	480.1	385.3	94.8	3.79	2,900	.79
22–23 to 24–25	12	225.4	211.7	13.7	.55	420	.24
24–25 to 26–27	13	138.9	113.9	25.0	1.00	770	.72
26–27 to 28–29	14	50.2	[8]57.1	([8])	([8])	([8])	([8])
28–29 to end	15	9.2	[8]18.0	([8])	([8])	([8])	([8])
5–6 to 30–31	16	636.0	595.6	40.4	1.62	1,240	.25
20–21 to 32–33	17	208.7	177.4	31.3	1.25	960	.60
32–33 to end	18	28.3	20.7	7.6	.30	230	1.06
Total		5,325.4	4,821.4	519.7	20.79	15,900	.39

[1]Breakdown of original capacity into estimated original ranges and segments was not attempted; 1971 ranges and segments (and their corresponding capacity) represent some lumping of 1963 survey segments and ranges because of waterhyacinth growth and mining operation obstruction.

[2]On basis of 1971 computations of original capacity, figures rounded.

[3]Figures rounded.

[4]Difference between original and 1971 capacity.

[5]Total volume divided by 25 years.

[6]Annual volume multiplied by 764.7 ton/acre-ft (35.11 lb/ft^3), rounded to the nearest 10 tons.

[7]Annual volume divided by original capacity.

[8]Larger capacity for 1971 than for original capacity may have resulted from improper survey techniques or from channel cleanout activities between 1964 and 1971. Sediment accumulation for these ranges was treated as zero rather than as a minus figure. Consequently, the sum of the Cidra capacity in 1971 and total sediment volume exceeds the original capacity figure.

(annual average loss, 0.59 percent). Sediment volume is 26 percent of total reservoir deposits. Unlike the other two arms, sedimentation in the Río Bayamón does not follow the downstream decreasing rule. Why this has happened is not clear.

Range 28–29 in segments 14 and 15 of the Río Bayamón may have been improperly oriented originally with respect to the stream channel. The 1964 report included a planimetric map showing the purported location of the range; but we could not find the range-end monuments for the 1971 study. The 1971 measurements of range length were three times larger than those reported in 1964. Range dimensions are used to compute volume of adjacent segments. So an increased capacity could have resulted from this measurement discrepancy. Another possibility is that the channel cleanout activities to preserve or improve the clearance of a bridge on state highway 787 carried out between 1964 and 1971 may have changed the range dimensions.

The downstream portion of the Río Bayamón, including segments 1–4, 6, generally conforms to the downstream decreasing rule except in segment 1 in which sediment increases because of the dam.[9]

Trap efficiency

Efficiency in trapping sediment depends on several factors: storage capacity and inflow; reservoir age, shape, and surface area; type of outlet and method of reservoir operation; and kind, size, and gradation of sediment. For normal ponded reservoirs, Brune (1953) described a relation between the capacity-inflow (C/I) ratio and the percentage of sediment trapped. The original C/I ratio for Cidra Reservoir was computed to have been 0.44, which gives a trap efficiency of 95 percent. The C/I ratio for reservoir conditions in 1971 was computed to be 0.40—a slight decrease but no change in trap efficiency.

Characteristics and distribution of sediment

Characteristics were determined from field observations of sample core materials and from laboratory analyses of representative samples (table 6 shows three such samples). The dry weight of all sediment samples taken ranged from 28.4 to 48.4 lb/ft^3; the average was 35.11 lb/ft^3 (0.56 g/cm^3). Clay averaged 34 percent; silt, 55 percent; sand, 10 percent; and larger materials, the remainder. Sediment was deposited in all segments in depths ranging from 0.1 to more than 4.7 ft (0.03–1.4+ m). Deepest deposits were in upstream segments.

Field measurements of suspended sediment loads in waters passing through the dam spillway and in downstream waters are not available, but the estimated annual tonnage indicates a low annual load. Since 1946, a

[9]Sediment is trapped at the base of the dam. Sedimentation surveys of Caoñillas and Loíza Reservoirs in Puerto Rico reported similar effects.

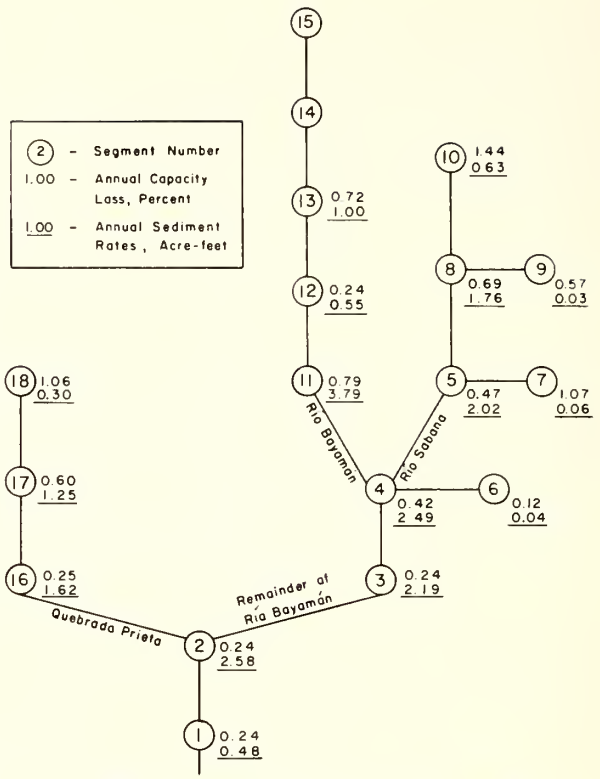


Figure 11.—Diagram of 1971 reservoir segments.

calculated 27.4 acre-ft of sediment has passed the dam gates and entered the downstream channel system. This figure was computed on the basis that the trap efficiency is 95 percent and that the total amount of sediment deposited in the reservoir is 519.7 acre-ft. At a weight of 35.11 lb/ft^3 (764.7 ton/acre-ft) of sediment, the 1.09 acre-ft that passes annually weighs 2.29 tons (equivalent to an average suspended load in downstream waters of 2.12 parts per million).

The average yearly surface runoff is 12,125 acre-ft of water. The daily runoff of 33.2 acre-ft is equivalent to a water flow of 16.7 ft^3/sec. Discharge over the spillway may or may not take place depending on consumptive demands.

Original design data for determining the relation of reservoir elevation to capacity or area were unavailable in 1971 for this study; however, by measuring range profiles and computing segment volume, it is possible to synthesize the relation. The total original capacity com-

Table 6.—Particle-size distribution of representative sediment samples by mechanical analysis

Range sampled	Coarse materials (>2 mm)	Coarse sand (2.0 to 0.42 mm)	Fine sand (0.42 to 0.074 mm)	Silt (0.074 to 0.002 mm)	Clay (<0.002 mm)
	percent	*percent*	*percent*	*percent*	*percent*
24–25	0.0	5.8	4.2	55.5	34.5
26–27	.0	3.8	8.0	60.2	28.0
28–29	7.8	12.0	19.7	38.3	22.2

puted by the synthetic method differs from the total computed for sediment determination by only 0.5 percent. Figure 12 is a graphical expression of the original capacity by elevation.

Effective storage was planned between the 1,322- and 1,270-ft elevations with dead storage below 1,250 ft. Segments 1 through 4 and segment 16 had about 360 acre-ft of dead storage (table 7). The 1971 survey showed that more than 64 percent (233 acre-ft) of dead storage was occupied by sediment. Segments 4 and 16 no longer had any dead storage available for incoming sediment. In segments still having dead storage space in excess of accumulated sediment deposits, segments 1, 2, and 3, sediment is continuing to build up in both dead and effective storage. In all segments upstream from segments 4 to 16, sediment is encroaching on effective storage. Figure 13 is a summary of pertinent reservoir data.

Calculation of erosion rates

One method of calculating soil erosion is based on land use, vegetative cover conditions, length and gradient of land slope, rainfall, and soil erodibility. Data must be available over a long period for all these factors to allow valid conclusions. In the Cidra watershed, changes in land use, field slope length (related to land use), vegetative cover, and watershed rainfall and runoff characteristics are not well known. Extrapolation of short-term data can give incorrect long-term predictions of erosion.

Another approach is to calculate gross erosion or the total amount of erosion from all possible causes, geologic processes, agricultural activities, and road, residential, commercial, and industrial construction.

For this report, the average gross erosion was calculated by using the sediment delivery ratio equation:

$$\text{sediment delivery ratio} = \frac{\text{sediment yield}}{\text{gross erosion}}$$

Figure 12.—Relation of water level elevation to storage capacity of reservoir.

Table 7.—Accumulated sediment and effective and dead storage capacity by segment

1971 segment No.	Original capacity	Original effective storage[1]	Original dead storage	1971 sediment accumulation
	acre-ft[2]	*acre-ft*[2]	*acre-ft*[2]	*acre-ft*[2]
1	198	151	47	12
2	1,074	873	201	64
3	912	853	59	55
4	597	562	35	62
16	636	618	18	40
Total	3,417	3,057	360	233

[1] Based on 1971 computations of original capacity.
[2] Rounded to the nearest acre-foot.

The sediment delivery ratio is the percentage of soil eroded from a drainage area that reaches a specific cross-sectional area downstream. The ratio can be estimated from various watershed characteristics: watershed relief, size of drainage area, stream order and length, bifurcation ratio, relief-length ratio, and drainage density. The relief-length characteristic (a mathematical relationship described by Roehl in 1962) was selected as the best indicator of sediment transport conditions in this rugged topography.

Relief-length factors were measured on U.S. Geological Survey topographic quadrangle sheets, and the sediment delivery ratio in percent for each major tributary drainage area was estimated (Quebrada Prieta, 47.8; Río Bayamón, 56.2; Río Sabana, 47.4). The average of these percentages, 50.5 percent, was used as the delivery ratio for the entire watershed drainage area.

From the sum of the measured 25-yr sediment volume of 519.7 acre-ft in the reservoir (table 5) and the estimated 27.4 acre-ft of sediment escaping the reservoir (average trap efficiency of 95 percent), the average sediment yield was determined to be 21.9 acre-ft/yr (16,733 ton/yr).

The equation for determining annual gross erosion is:

$$\text{gross erosion} = \frac{\text{sediment volume}}{\text{average delivery ratio}}$$

$$\text{gross erosion} = \frac{16{,}733 \text{ ton/yr}}{0.505}$$

$$\text{gross erosion} = 33{,}135 \text{ ton/yr}$$
$$= 43.3 \text{ acre-ft/yr}$$

To properly evaluate the total erosion picture, the kind, distribution, erodibility, and bulk density of the watershed soils must be considered. The kinds of soil and the distribution, acreage, and proportionate extent of the soil associations are discussed earlier.

Some soils erode more easily than others. Extensive research (Wischmeier and Smith 1965) has provided numerical "K" values to express a soil's propensity to

erode relative to that of other soils. The relative erodibility value for the major soil associations[10] is shown in table 8. Erodibility value and proportionate extent of the two soil associations were used to determine the relative importance (potential) of the soils in each association as an erosion source. Even though association 6 occupies a smaller part of the watershed, soils in that association have a much greater potential for erosion (eight times greater) than soils in association 7.

Erosion estimates for the drainage area of each major tributary were based on the estimated sediment delivery of each drainage and the average bulk density (weight per unit volume) of soils in each major association. Annual soil losses for the Río Bayamón, Quebrada Prieta, Río Sabana, and the remainder of Río Bayamón to the dam totaled 43.3 acre-ft.

The total annual soil loss for these drainages multiplied by the percentage of weighted erosion potential gives the soil loss in acre-feet by soil association. The annual soil loss in tons can be calculated by using the average bulk density in tons per acre-foot. The total annual watershed erosion is nearly 73,000 tons; it averages 14.0 ton/acre of land area, which is equivalent to a soil loss of 0.09 in./yr (0.229 cm/yr).

Reduction of sedimentation and erosion

Cultivated land in the steep upland areas and land with residential and industrial construction are the two most critical sources of erosion in the Cidra watershed. Proper land treatment can reduce this erosion and the resulting sediment in the reservoir.

The average erosion rate for the watershed in 1971, 14 ton/acre/yr, is well above the environmentally acceptable erosion rate of 4 tons/acre/yr for land in agricultural use. Most of the cultivated land in the steep areas requires intensive conservation treatment. Conservation measures particularly needed include conversion to less intensive use, improved rotations, contour cultivation, stripcropping, crop residue management, vegetative or rock barriers, complete water disposal systems, and proper fertilizing and liming.

Improperly handled coffee land is a major source of reservoir sediment. Conservation measures that can cut soil losses include maintaining a vegetative cover, making provision for water disposal, and constructing terraces for individual trees.

Parts of the watershed should be forested. Good woodland management practices will increase the erosion protection afforded these areas as well as extending the lifespan of the forests themselves.

Much of the watershed is particularly well suited to grass production. A major shift to grassland farming is highly desirable to reduce erosion. Existing pastures can be improved by reseeding with better varieties of grass, by liming and fertilizing, and by controlling grazing.

In recent years there has been a decrease in the acreage of cropland and an increase in the acreage of pasture. Theoretically, this should have reduced the amount of sediment entering the reservoir. But residential and industrial construction has increased and now rivals cropland as a major supplier of sediment. Gravel and sand mining on the flood plains appears to be contributing significantly to the sediment buildup in parts of the reservoir. Erosion from the mined areas is also creating hydrologic changes that affect stream channel stability.

The Cidra watershed is within the boundary of Torito Puerto Rico soil and water conservation district. The Soil Conservation Service, U.S. Department of Agriculture, provides technical assistance to landowners who have signed up with the districts as cooperators. By June 1971, nearly 828 cooperators had signed conservation agreements with the district. Conservation practices now being applied include brush management, chiseling and subsoiling, conservation cropping systems, contour farming, critical area planting, crop residue management, diversions, grassed waterways or outlets, hillside ditches, land smoothing, pasture and hayland management, pasture and hayland planting, pipelines,

[10] Soil Conservation Service, U.S. Dep. Agric. Hydrologic group K and T factors of [soil] series having type locations in the south region. Soil Survey, South Tech. Serv. Cent., Fort Worth, i-v, tables. 1971.

Table 8.—Soil erosion in the Cidra watershed

Soil association	Watershed area	Average "K" value	Sediment contribution (weighted potential)	Average bulk density			Estimated soil loss	
	percent		*percent*	*g/cm³*	*lb/ft³*	*ton/acre-ft*	*acre-ft*	*tons*
6	24.2	0.17	74.5	1.20	74.71	[1]1,630	[2]32	[3]52,700
7	70.5	.02	25.5	1.33	83.02	[1]1,810	[2]11	[3]20,000
Total	[4]94.7		[5]100.0				43	72,700

[1] Rounded to the nearest 5 ton/acre-ft.
[2] Rounded to the nearest acre-ft.
[3] Rounded to the nearest 100 tons.
[4] Remaining 5.3 percent is in water.
[5] For two major soil associations.

RESERVOIR SEDIMENT
DATA SUMMARY
SCS-34 Rev. 6-66

LAGO (LAKE) CIDRA
NAME OF RESERVOIR

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

80-
DATA SHEET NO.

1022290526

DAM

1. OWNER P.R. Water & Sewer Auth	2. STREAM Río Bayamón	3. STATE
4. SEC. TWP. RANGE	5. NEAREST P.O. Cidra, P.R.	6. COUNTY
7. LAT. 18° 11'41" LONG. 60°08'28"	8. TOP OF DAM ELEVATION 1,338.6ft	9. SPILLWAY CREST ELEV. 1,322.2ft

RESERVOIR

10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. ORIGINAL SURFACE AREA, ACRES	13. ORIGINAL CAPACITY, ACRE-FEET	14. GROSS STORAGE, ACRE-FEET	15. DATE STORAGE BEGAN
a. FLOOD CONTROL					
b. MULTIPLE USE					1946
c. POWER					
d. WATER SUPPLY	1,321.8 ft	274.4	4,965	5,325	16. DATE NORMAL OPER. BEGAN
e. IRRIGATION					
f. CONSERVATION					1946
g. INACTIVE	1,270.0 ft	1/	360	360	

17. LENGTH OF RESERVOIR 6.5 2/ MILES		AV. WIDTH OF RESERVOIR 0.2	MILES
18. TOTAL DRAINAGE AREA 8.12 SQ. MI.		22. MEAN ANNUAL PRECIPITATION 70.0	INCHES
19. NET SEDIMENT CONTRIBUTING AREA 7.7 SQ. MI.		23. MEAN ANNUAL RUNOFF 28.0	INCHES
20. LENGTH 2.8 2/ MILES	AV. WIDTH 2.9 MILES	24. MEAN ANNUAL RUNOFF 12,125 3/	AC.-F T.
21. MAX. ELEV. 1,800 ft	MIN. ELEV. 1,257 ft 4/	25. ANNUAL TEMP · MEAN RANGE	

WATERSHED

SURVEY DATA

26. DATE OF SURVEY	27. PERIOD YEARS	28. ACCL. YEARS	29. TYPE OF SURVEY	30. NO. OF RANGES OR CONTOUR INT.	31. SURFACE AREA, ACRES	32. CAPACITY, ACRE-FEET	33. C/I. RATIO, AC.-FT. PER AC.-FT.
11/46	0	0	-	-	274.4	5,325.4	0.439
11/15-22/71	25.0	25.0	Range (D)	18	274.4	4,821.4 5/	0.398

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIPITATION	35. PERIOD WATER INFLOW, ACRE-FEET			36. WATER INFL. TO DATE, AC.-FT.	
		a. MEAN ANNUAL	b. MAX. ANNUAL	c. PERIOD TOTAL	a. MEAN ANNUAL	b. TOTAL TO DATE

26. DATE OF SURVEY	37. PERIOD CAPACITY LOSS, ACRE-FEET			38. TOTAL SED. DEPOSITS TO DATE, ACRE-FEET		
	a. PERIOD TOTAL	b. AV. ANNUAL	c. PER SQ. MI.-YEAR	a. TOTAL TO DATE	b. AV. ANNUAL	c. PER SQ. MI.-YEAR
11/15-22/71	504.0 5/	20.2 5/	2.6 5/	519.7 6/	20.8 6/	2.7 6/

26. DATE OF SURVEY	39. AV. DRY WGT., LBS. PER CU. FT.	40. SED. DEP., TONS PER SQ. MI.-YR.		41. STORAGE LOSS, PCT.		42. SED. INFLOW, PPM	
		a. PERIOD	b. TOTAL TO DATE	a. AV. ANN.	b. TOT. TO DATE	a. PERIOD	b. TOT. TO DATE
11/15-22/71	35.11	2,064.5	2,064.5	0.39 6/	9.76 6/		

1/ Unknown--elevation/area data unavailable.
2/ Length from dam to end Río Sabana arm.
3/ Top of closed gates.
4/ Stream channel at base of dam.
5/ Net capacity; corrected to include computed capacity increases in segments 14 and 15.
6/ Based on total measured sediment volume.

Figure 13.—Summary of sedimentation data for Lake Cidra Reservoir.

1022290526

ponds, spring developments, tree planting, troughs or tanks, wells, and woodland improvement.

A very substantial reduction in the sediment rate of Cidra Reservoir can be achieved if the landowners accelerate their programs of conservation treatment. If erosion can be reduced more than 70 percent, it will reach the acceptable rate of 4 ton/acre/yr. Reduced sedimentation will save money on water treatment costs and improve the lake water for fish and for recreation and increase its esthetic value.

Conclusions and recommendations

The current average rate of sediment accumulation, 43.3 acre-ft/yr (about 14 ton/acre/yr), threatens to curtail the life expectancy of Lake Cidra as a dependable holding basin of water for potential rural and urban needs. Control of soil erosion to tolerable levels, about 4 ton/acre/yr, can reduce annual erosion in the watershed by more than 70 percent and the corresponding sediment build-up in the reservoir. This would extend the life of the reservoir several hundred more years.

Soil and water conservation practices can reduce erosion and increase crop production. Reduced sedimentation results in lower treatment costs of water for domestic and industrial uses. Less sediment means clearer water. This will increase production of fish and their natural food. Clearer water encourages more recreation use and increases esthetic value.

On much land, conservation treatment needs to be intensified and expanded. On flood plains having sand and gravel mining, adoption and enforcement of erosion control regulations can decrease sediment contributions.

Technical assistance to individual landowners for planning and carrying out conservation practices is available through local soil and water conservation districts. Assistance to groups of landowners is available through federal government programs, such as the Resource Conservation and Development Program administered by SCS.

Literature cited

Arnow, T., and J. W. Crooks. 1960. Public water supplies in Puerto Rico. U.S. Geol. Surv. in cooperation with P.R. Commonw. Water Resour. Bull.

Brune, G. M. 1953. Trap efficiency of reservoirs. Am. Geophys. Union Trans. 34(3): 407–418.

Census Bureau, U.S. Dep. Commer. 1960. United States census of population, 1960. *In*: United States summary, general population characteristics. p. 1-143—1-175.

_____ 1964. United States census of agriculture. 1, pt. 52, Puerto Rico.

_____ 1968. Statistical abstract of the United States, 1968. ed. 89.

_____ 1972. 1969 census of agriculture. 1, pt. 52, Puerto Rico. 17 p.; tables, append.

Eakin, H. M. 1936. Silting of reservoirs. Ed. by C. B. Brown. U.S. Dep. Agric. Tech. Bull. 524, 142 p.

Goitia, J. R. 1970. Aquatic weed control in Puerto Rico. Am. Soc. Civil Eng. Meet., Fla. sect. pap.

Gottschalk, L. C. 1951. Measurement of sedimentation in small reservoirs. Am. Soc. Civil Eng. Proc. 1951, Separate 55.

Pease, M. H., Jr., and R. P. Briggs. 1960. Geology of the Comerio Quadrangle, Puerto Rico. U.S. Geol. Surv. Misc. Publ.

Roehl, J. W. 1962. Sediment source areas, delivery ratios and influencing morphological factors. Presentation at the I.A.S.H. Symposium on Land Erosion, Oct. 1962. I.A.S.H., Land Erosion Comm. Publ. 59, p. 202–213.

Schneider, W. J., compiler. 1968. Water data for metropolitan areas: A summary of data from 222 areas in the United States. U.S. Geol. Surv. Water-Supply Pap. 1871, p. 314.

Sheda, H. E., and J. Legas. 1968. The condition of concrete dams, Commonwealth of Puerto Rico. Sec. 15—Condition of Loiza dam. Bur. Reclam., U.S. Dep. Int. Prepared for P.R. Water Resour. Auth. and P.R. Adqueduct and Sewer Auth.

Wischmeier, W. H., and D. D. Smith. 1965. Predicting rainfall-erosion losses from cropland east of the Rocky Mountains. Agric. Res. Serv., U.S. Dep. Agric., Agric. Handb. 282. 47 p.

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